AN INVESTIGATION OF

AIR TRANSPORTATION TECHNOLOGY

AT THE

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SUMMARY OF RESEARCH ACTIVITIES

1. INTRODUCTION

There are three completed projects and three continuing research activities under way under the sponsorship of the FAA/NASA Joint University Program as the 1990-91 period ends. There were a number of publications during the year and a set of Annotated References to them is provided in Section 3. As well, the complete conference paper is included for a few of these references. A brief summary of the continuing research activities is provided in the next section.

2. REVIEW OF CONTINUING RESEARCH ACTIVITIES

2.1 Wanke, C., and Hansman, R. J., Hazard Assessment and Cockpit Presentation Issues For Microburst Alerting Systems.

Introduction

Low altitude wind shear events, and in particular microbursts, are the leading weather-related cause of fatal aviation accidents in the U.S. For this reason, wind shear hazard detection and alerting system development is a very active area of research, and has been a focus of the Joint University Program for several years. The variety of systems under development for wind shear detection and ground-to-air datalink, combined with the advent of electronic cockpit instrumentation, allow many options for implementation of an

integrated microburst warning system. Recent work at MIT has concentrated on two facets of this problem: (1) microburst hazard assessment, and (2) cockpit display of microburst alerts to flight crews.

Microburst Hazard Assessment

The first task for microburst alert generation is to combine data from several systems, which use different measurement techniques, into an estimate of the hazard posed to aircraft by a particular wind shear event. This must be done as accurately as possible to minimize both missed and unnecessary alarms. However, the danger to aircraft posed by a microburst is <u>not</u> a directly measurable quantity. Thus, a microburst "hazard criterion" is needed, a quantity which can be directly measured or inferred from the available measurements. One example of such a criterion, currently used by the Terminal Doppler Radar System (TDWR) is maximum wind change across the microburst. Alternatives to this are shear-based or energy-based criteria which are more difficult to measure but relate more directly to the effect of the windfield on the dynamics of an aircraft.

A technique based on batch flight simulation has been developed to evaluate some candidate hazard criteria.[1] Simulated approaches through numerically-modeled microbursts are flown, and a quantitative measure of approach degradation due to the windfield, a "microburst impact parameter," is computed. This measure includes both glideslope deviations and airspeed losses. The candidate microburst hazard criteria are then correlated with this microburst impact parameter. The value of the linear correlation coefficient is indicative of the usefulness of that criterion for evaluating the microburst hazard to aircraft.

The results, using 12 modeled microburst windfields in several geometrical configurations, indicate that shear-based (airspeed change per unit distance) and energy-based measures correlate very well with the microburst impact parameter. Also, maximum wind change was found to correlate very poorly. Further work is being done to extend these results to cover additional high-resolution microburst windfields, and to use these results to define "hazard thresholds" for accurate alert generation.

Cockpit Display of Microburst Alerts

Once alerts are generated, they need to be quickly and effectively disseminated to the flight crew. Recent work at MIT on this issue has focused on use of a digital datalink and electronic cockpit displays to graphically present microburst alerts to the pilot. A previous piloted simulator experiment performed earlier in this program demonstrated that graphical alerts are significantly more

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[1] Wanke, C., and Hansman, R.J., "Alert Generation and Cockpit Presentation for an Integrated Microburst Alerting System," AIAA Paper 91-0260, January 1991.

effective than verbal or alphanumeric alerts.[2] A second experiment to further explore the use of graphical alerts was then designed and run in June of 1991. This experiment tested several different graphical alert formats using the MIT Advanced Cockpit Simulator, a part-task simulator of a modern transport aircraft with electronic cockpit displays. Alerts were presented on the Electronic Horizontal Situation Indicator; an example of a multi-level alert format is shown in Figure 1. Some of the issues being examined in this experiment are:

- Is presentation of microburst alerts on the EHSI display clear and effective?
- Should the available measurements be used with a hazard threshold to generate a single-level alert for "hazardous" microbursts only, or should multiple levels of intensity be displayed?
- Should measurements from all of the available sensors be combined to form a single "fused" alert, or should alerts from different sources be independently displayed?
- What are the procedural implications of displaying graphical alerts, i.e., does the positional information present in these alerts cause the pilot to significantly alter his avoidance strategy?

Analysis of the data from this experiment is in progress; nine active airline pilots have participated to date. The experiment involves flying a total of 12 approach scenarios with the simulator, using a variety of graphical alert formats. Preliminary results indicate that multi-level alerts are more desirable than single level alerts, and that display of alerts on the EHSI was found to be very clear and useful by the pilots. Further analysis is underway, and results will be presented at the next JUP quarterly meeting.

2.2 Hahn, E., and Hansman, R. J., The Situational Awareness Effect of Automated ATC Datalink Clearance Amendments.

Introduction

Among the capabilities envisioned for the future datalink (i.e. digital ground to air communications) system will be the use of these aircraft specific communications to supplement and possibly replace most routine Air Traffic Control (ATC) messages. By reducing the volume of ATC communications, including en route and terminal clearance amendments, datalink would relieve the already congested VHF voice frequencies. Additionally, having information being received in digital form makes it extremely easy for the

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2 Wanke, C., Chandra, D., Hansman, R. J., and Bussolari, S.R., "A Comparison of Voice and Datalink for ATC Amendments and Hazardous Wind Shear Alerts," 4th International Symposium on Aviation Space Safety, Toulouse, France, 20-22 November, 1990.

aircraft Flight Management Systems to read the information directly, increasing efficiency and reducing data transfer errors. However, the automation of datalinked ATC clearance amendments could adversely affect the flight crew's situational awareness by reducing their level of involvement in the amendment process. This project is investigating the effects of information presentation mode and amendment procedures on situational awareness of possible implementations of datalink.

Current Work

Work is proceeding on a part-time simulation study using the MIT Advanced Cockpit Simulator. The experiment centers on the information presentation mode and amendment procedures in possible ATC datalink implementations. Data is collected on the error detection capabilities of pilots when the procedure is altered to change the number of times the airline pilot subject must review the data during the process. In particular, the need for keying in of data and also the need for a readback to ATC is varied independently between scenarios. In addition, the mode of presentation is also independently varied between verbal, textual, and graphical formats to investigate whether one presentation mode is better than others. Data will also be collected on the pilot's time performance and subjective preferences.

The scenarios will simulate the Northeast Corridor during heavy traffic and thunderstorm conditions in order to increase the number of clearance amendments given to the pilot. Each is designed around two separate kinds of errors: the aircraft will be cleared into heavy thunderstorm cells and also will be routed incorrectly (i.e. to the wrong airport, the wrong approach fix, or on an illogical path). Each subject pilot will fly ten scenarios, each of which will have a different combination of presentation mode and amendment procedure. Eighteen subjects are currently being sought to participate in the experiment. The testing stage of the experiment is projected to terminate in September.

3. ANNOTATED REFERENCES OF 1990-91 PUBLICATIONS

3.1 Chi, Zhihang, A Graphic Simulation System for Adaptive, Automated Final Approach Spacing, Flight Transportation Laboratory Report 91-3, June 1991, Flight Transportation Laboratory, MIT, Cambridge, MA, 02139

As airline industry grows and air traffic increases drastically, terminal airspace around busy airports is becoming more and more crowded. To accommodate the soaring demand for use of airports, a plausible and profitable way is to improve the efficiency of existing airports. An automated final approach spacing system can improve the efficiency as well as alleviate the workload of air traffic controllers.

In this research we develop an automated adaptive and interactive Final Approach Spacing Advisory (FASA) system to be used in future at busy airports. Our system is able to generate and update final arrival paths for aircraft and guarantees that the aircraft land as scheduled and safely spaced. It prompts air traffic controllers for calls of turns and speed reductions until they merge into the approach center line. These automated prompts are adaptive to errors in the execution of the arrival paths due to winds or pilot response. Also our system grants the controllers the ability to manually alter the landing schedule without violating constraints and regulations.

It is assumed that a separate metering system has developed a plan for landing aircraft. This landing schedule is represented to the ATC controller in FASA as a sequence of "schedule boxes" or "slot markers" moving along the extended center line. The ATC controller has some degree of control over the planned landings by moving these slot markers. A range of feasible changes in the slot position ("feasible interval") can be displayed. If a slot is moved rearwards to delay its landing, or if it arrives late for its slot on the center line, all subsequent slot markers will automatically shift rearwards to maintain safe spacings, and the automated prompts are then based on the new plan. If an aircraft arrives early, slots are not shifted frontwards automatically, but if any aircraft arrives ahead of its slot and will violate safe separations before touchdown, an alert is given to the controller. The mathematical methods used to implement this system are capable of incorporating a large variety of constraints and other interactive features.

The FASA system was implemented on an Apollo Unix workstation in the C language and a graphical simulation using X-Windows was developed to test prototypical traffic situations for a single runway. The images of the elements of the FASA system, such as aircraft, slot markers and extended runway center line, are drawn in different colors on the color display of the Apollo workstation. The images of aircraft move along the runway center line. Prompts for calls of turns and speed reductions are implemented as the blinking of the images of the relevant aircraft. Error alerts are implemented as the change of colors of the relevant images. The user of our simulation program is given the ability to mouse any slot markers, drag them along the runway center line and put them anywhere within the feasible interval mentioned earlier.

The future research effort will extend the logic to incorporate planning for takeoffs, interactive insertion of missed approaches into the landing plan, and multiple runway operations. All of these features are easily implementable by extending the methods used in this thesis to develop FASA.

3.2 **Hazelton, Lyman R., An Expert System for Temporal Planning with an Application to Runway Configuration Management, Flight Transportation Laboratory Report 91-1, February 1991, Flight Transportation Laboratory, MIT, Cambridge, MA, 02139.**

The centralized Air Traffic Flow Control system depends critically on correct airport capacity estimates for its success. This requirement demands that area supervisors, responsible for the control facilities of the airports, construct a realistic *schedule* of the runway configurations to be used during the next several hours of operation. Constructing such a schedule is a difficult task, as it depends on several time dependent, strongly interacting factors. These variables include the airport ceiling and visibility, the wind speed and direction, the operational status of navigational aids, the expected traffic demand, noise abatement procedures and time of day, runway maintenance and repairs, and snow and ice removal. A computer program to weigh these factors and generate such a schedule would be very helpful and could have a major economic impact.

Significant problems stand in the way of creating a general scheduling program using standard techniques. Because each airport has difficult runway geometry, a different surrounding geography and population distribution, and different weather patterns, each scheduler program must be customized for the airport at which it is to operate. Using standard programming languages and techniques to create so many unique programs would be exorbitantly expensive. Further, the programs would require periodic updates to reflect changes in the economy and patterns of use at each airport, adding to the cost. Finally, some of the factors involved are not easily quantifiable, making the standard numerical methods of operations research difficult to apply.

Rule based "expert system" programs "reason", using logic, about a problem rather than just computing numerical results. They possess abilities which give them distinct advantages in the kind of problem domain typically encountered in Air Traffic Control: their structure consists of a standardized central "inference engine" and an easily customized set of rules and facts about a particular application; they can be built incrementally and are more easily maintained than traditional programs; and they can provide explanations of the logical processes used to make a decision, which can immensely simplify debugging.

At the time that this research was begun, there was a significant obstacle to using an expert systems approach, as well. While the program of runway configuration management clearly requires the ability to reason about time, there were no well defined mechanisms for carrying out this kind of reasoning in the logic of an expert system. In fact, there was almost no theoretical work in the area of temporal logic upon which one might base such a mechanism.

This research describes a number of powerful new ideas and techniques which extend the range of applicability of expert systems to temporally dependent problems. The most important of these is the description of a representation and a set of mechanisms which can be added to standard logic in order to reason about persistence. Also included are methods necessary to reason about irreversible actions. Implementation of these new ideas and mechanisms extends the temporal reasoning capabilities of an expert system inference engine so that it can successfully be applied to problems in Air Traffic Control such as runway configuration management. Indeed, they are of such a fundamental nature that they are applicable to a wide variety of planning and scheduling problems, perhaps including crew maintenance scheduling, space shuttle launch sequence scheduling, and autonomous robot task scheduling.

3.3 **Yamaguchi, K., and Hansman, R. J., Deterministic Multi-Zone Ice Accretion Modeling, AIAA-91-0265, AIAA 28th Aerospace Sciences Meeting, January 1991.**

A multi-zone predictive analytical model was created to describe the growth of ice on aerofoil leading edges under glare icing conditions. Comparison with experimental ice shapes showed good agreement. (See copy of paper included.)

3.4 **Wanke, C., and Hansman, R. J., Alert Generation and Cockpit Presentation for an Integrated Microburst Alerting System, AIAA-91-0260, AIAA 28th Aerospace Sciences Meeting, January 1991.**

The issues of providing a cockpit alert for microbursts which combines ground and air-based detection systems are investigated. An experiment has been designed to evaluate candidate graphical cockpit displays which uses a part-task piloted simulator. (See included paper.)

3.5 **Dershowitz, Adam L., and Hansman, R. J., Passive Infrared Ice Detection for Helicopter Applications, paper presented at 46th Annual Forum of American Helicopter Society, Washington, DC, May 1990.**

A technique is proposed to detect remotely the icing on rotor leading edges by using passive infrared thermometry to detect the warning caused by the release of the latent heat of fusion as supercooled water freezes. (See included paper.)